Impact of the Atlantic Warm Pool on North American Rainfall

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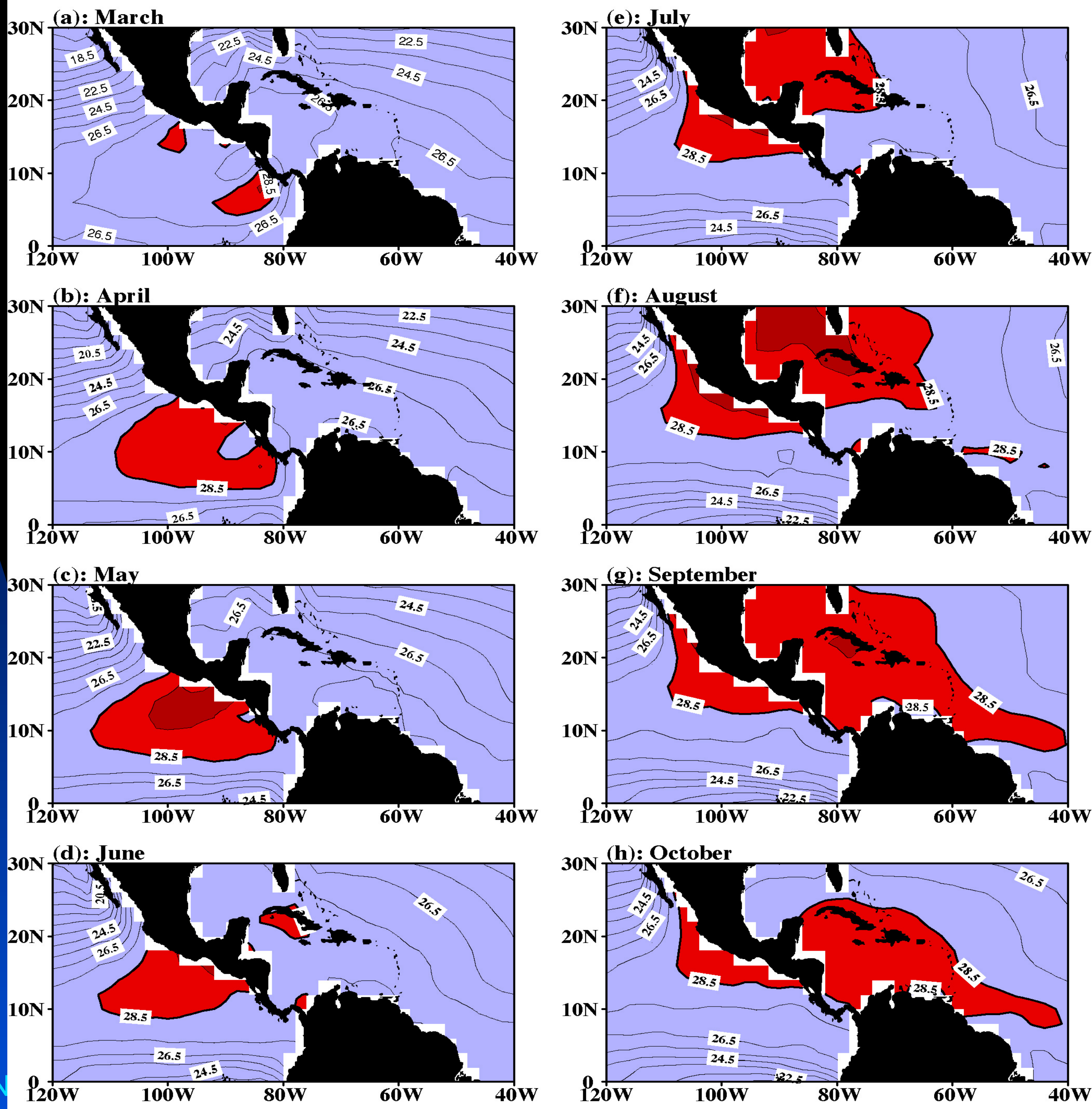
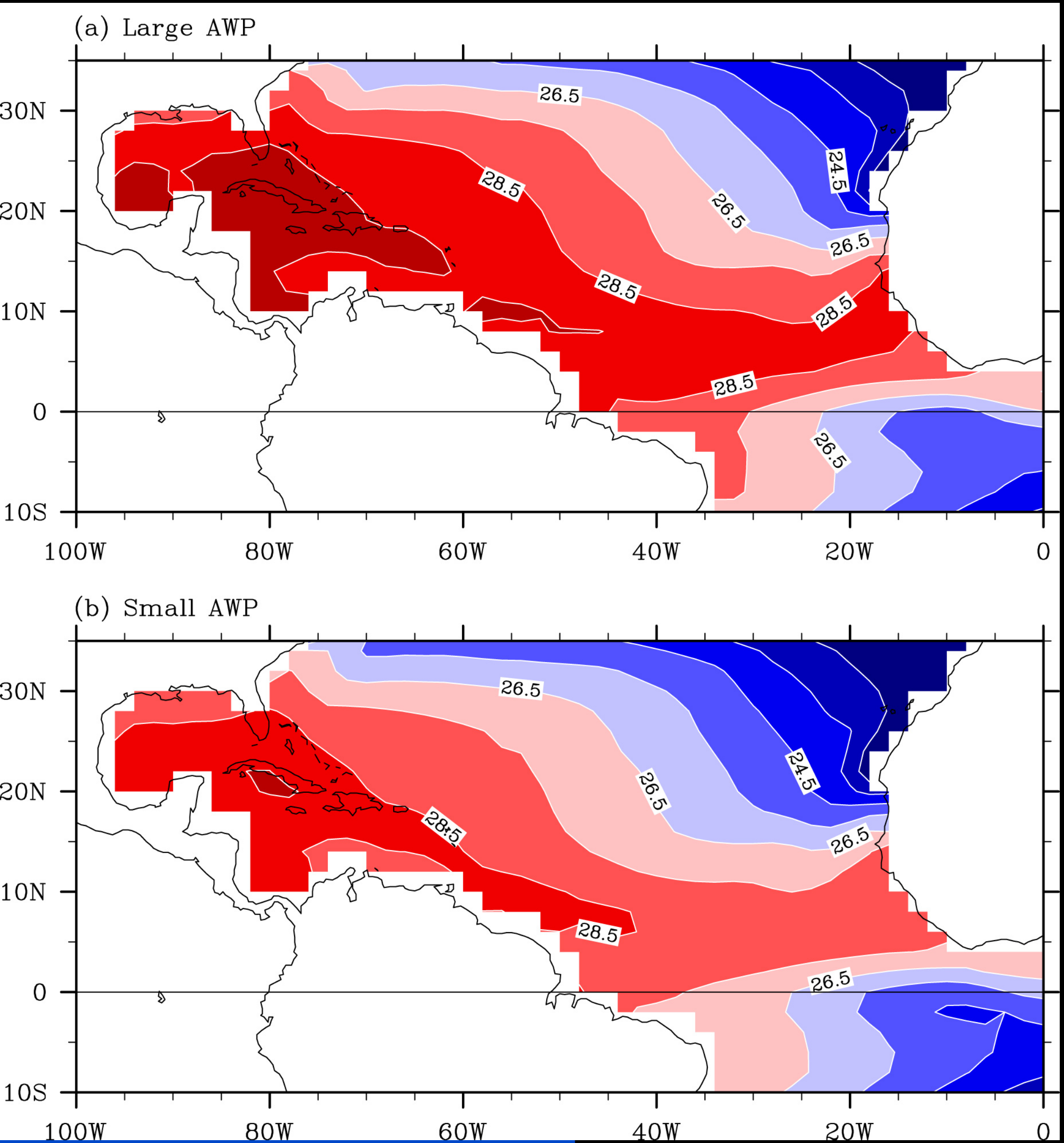
Wang & Enfield (2001, *GRL*) named the Western Hemisphere warm pool (WHWP).

SST ≥ 28.5°C

Focus on the Atlantic side of WHWP (AWP).



SST Composite of the Atlantic Warm Pool (AWP)



- ERSST data.
- AWP variability is large.
- Large AWPs are almost three times larger than the small ones.

Why Study the Atlantic Warm Pool (AWP)?

- **ENSO impacts climate mainly in winter; we need a value-added paradigm for *summer* climate prediction. This is the priority season for the AWP region, and ENSO is insufficient.**

- **The Indo-Pacific and Atlantic compete with each other and the atmosphere responds to inter-basin anomalies. We can no longer afford to make projections based only on the Pacific.**

- **Here we show that the AWP affects North American rainfall in both the cold and warm seasons, but with different mechanisms.**

- **The AWP is the path of or a birthplace of tropical cyclones.**

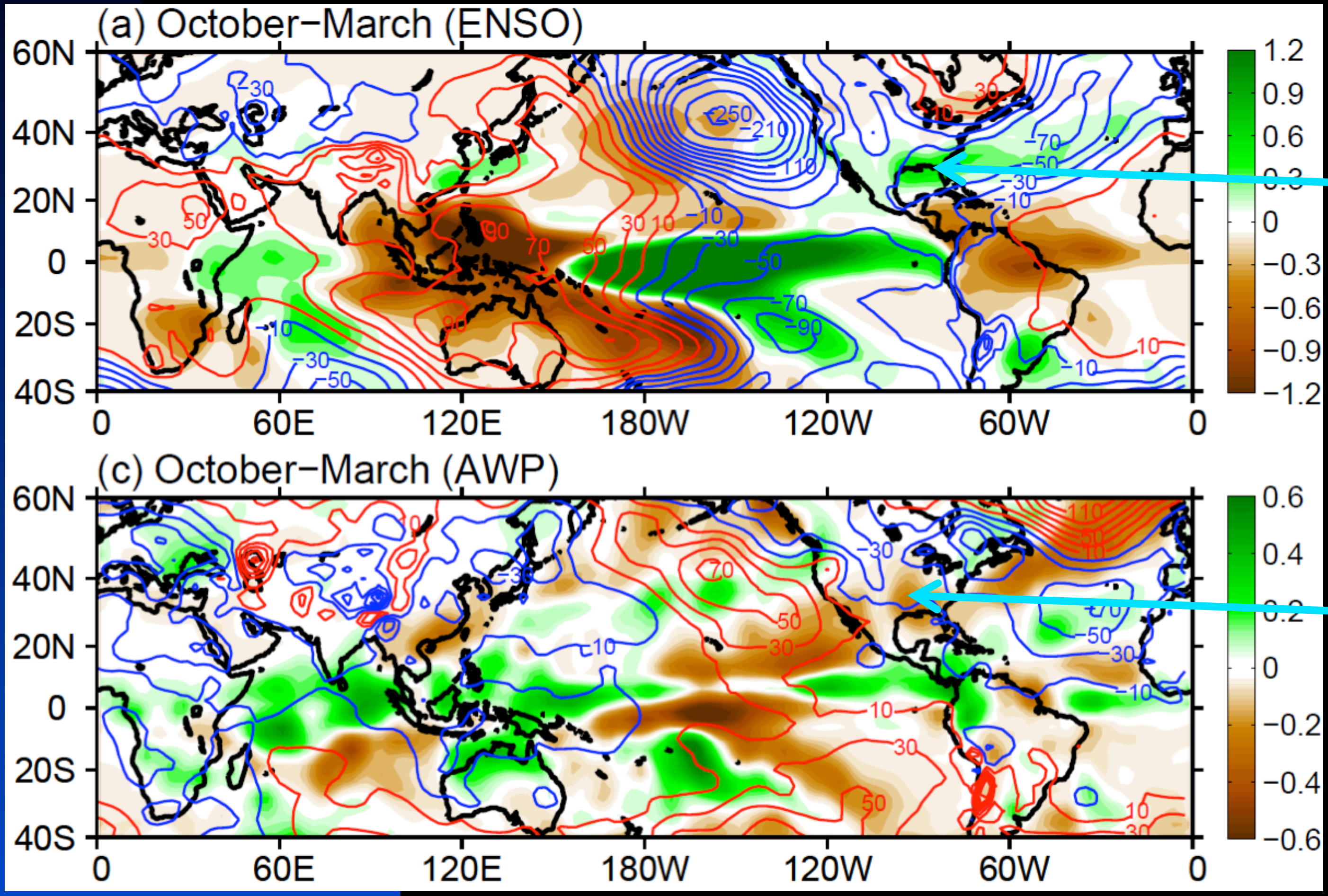
- **The moisture transport from the AWP is related to tornado activity in the central U.S.**

Observations: Rainfall (GPCP) and SLP (Reanalysis)

Multiple regressions of rainfall & SLP onto Nino3.4 and AWP indices during the *cold* season (October to March)

ENSO

AWP



Wet

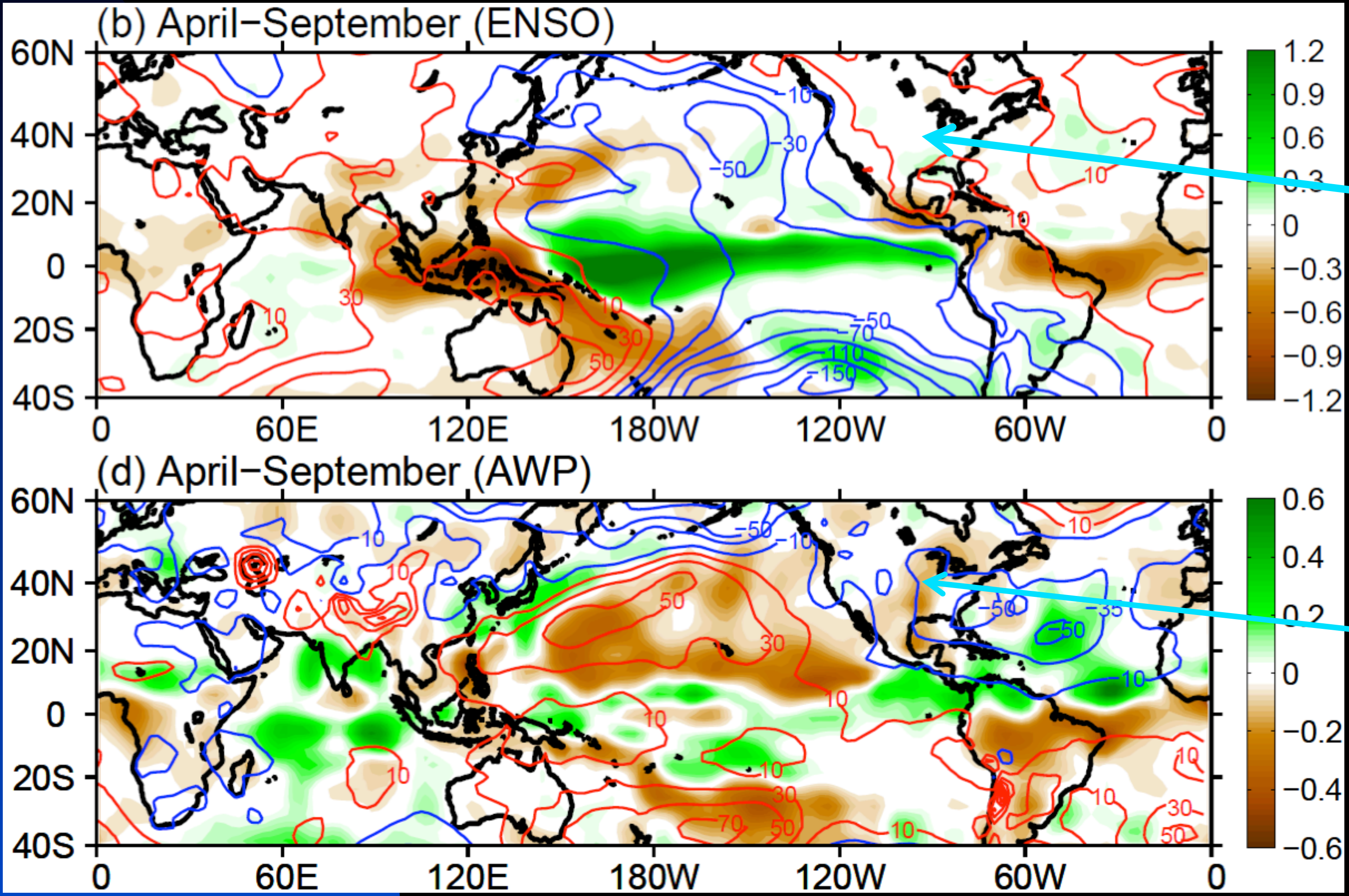
Dry

Observations: Rainfall (GPCP) and SLP (Reanalysis)

Multiple regressions of rainfall & SLP onto Nino3.4 and AWP indices during the *warm* season (April to September)

ENSO

AWP



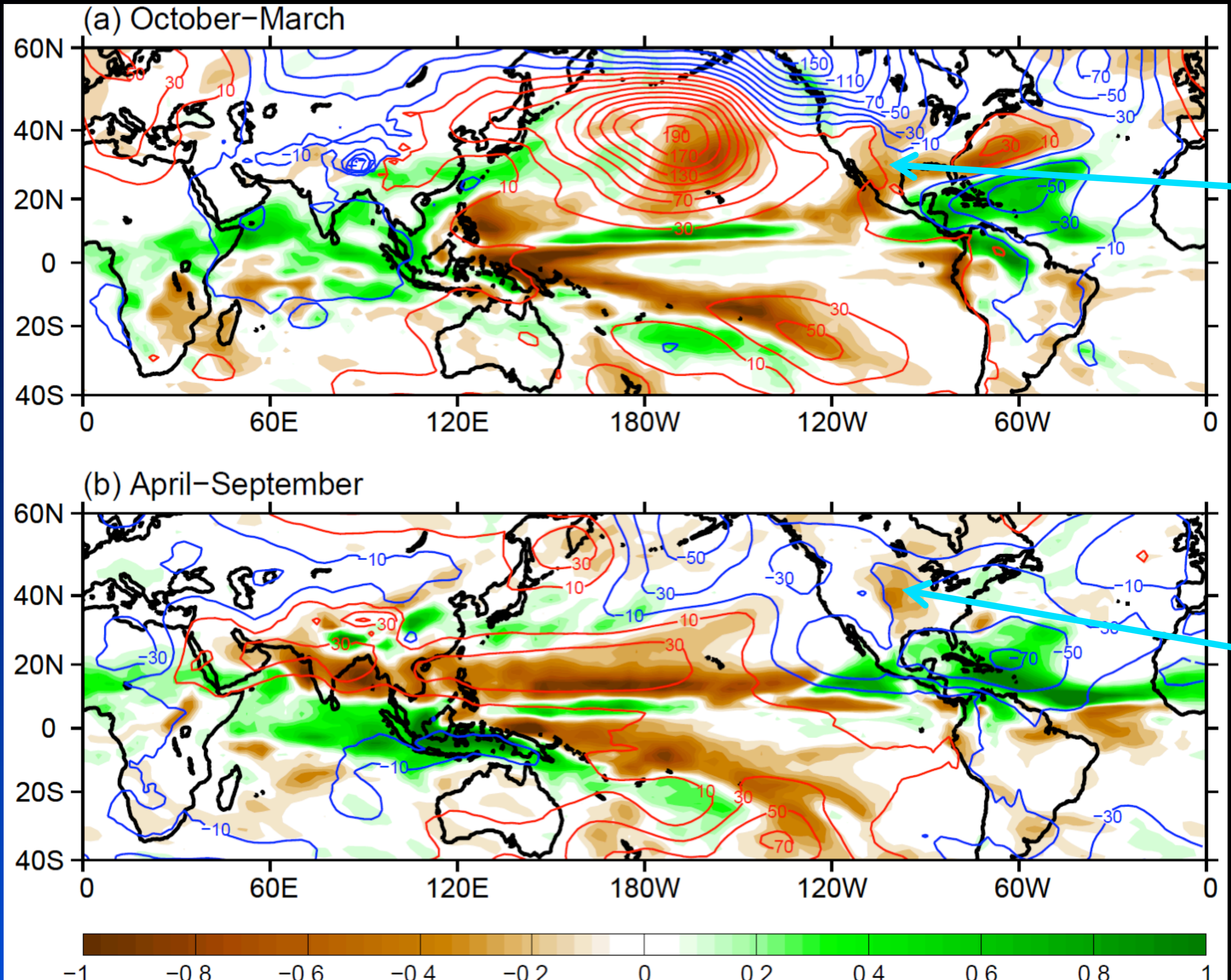
Insignificant

Dry

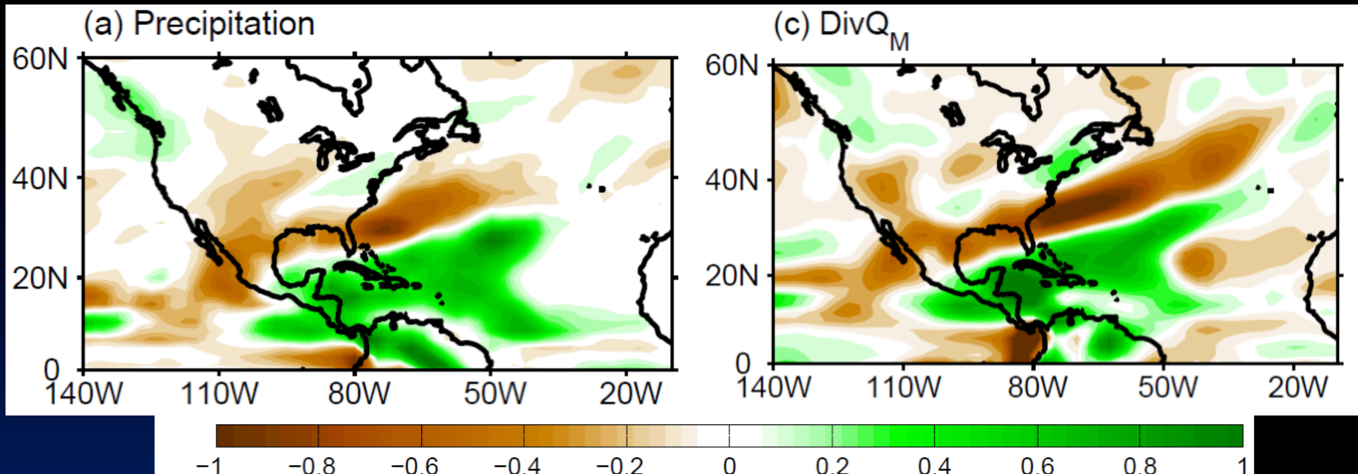
Coupled Model Experiments: NCAR Community Earth System Model (CESM1.0.4)

- SSTA composites for large and small AWPs are first computed by using ERSST version 3.
- Coupled model is integrated for 1500 years without climate shifts.
- Control (CTRL) run: The ocean and atmosphere are fully coupled except in the AWP region where we relax the model-produced SST to model climatological SST (from last 100 years of 1500 year model run).
- Large AWP (LAWP) run: The ocean and atmosphere are fully coupled except in the AWP region where we relax the model-produced SST to model climatological SST added with large AWP SSTA composites.
- Small AWP (SAWP) run: The ocean and atmosphere are fully coupled except in the AWP region where we relax the model-produced SST to model climatological SST added with small AWP SSTA composites
- The (LAWP – SAWP)/2 runs are taken as the AWP response.

Model rainfall & SLP response to the AWP: (LAWP – SAWP)/2 runs



Moisture Budget in the Cold Season: (LAWP-SAWP)/2 runs

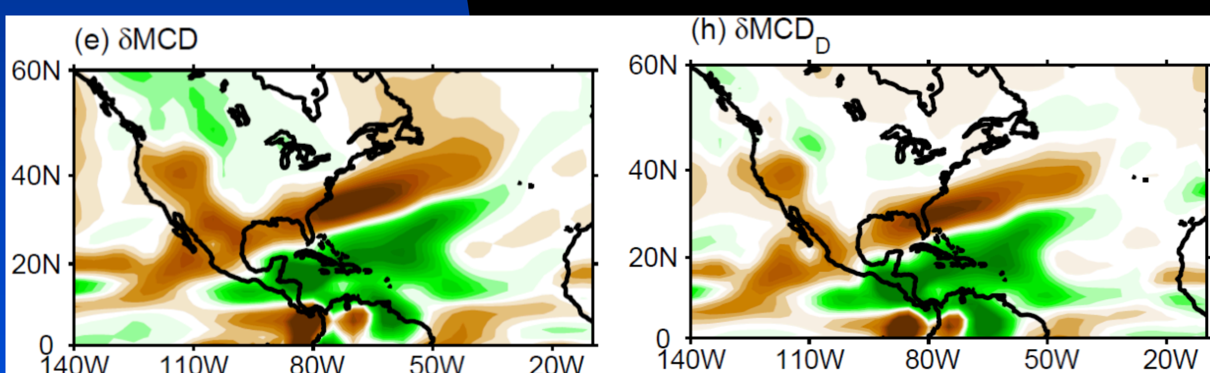


$$-\nabla\cdot\left(\frac{1}{g}\int_0^{p_s}(\overline{U}\overline{q})\,dp\right)$$

The change of $DivQ_M$ can be further separated into change by mean circulation dynamics (δMCD) and change by thermodynamics (δTH):

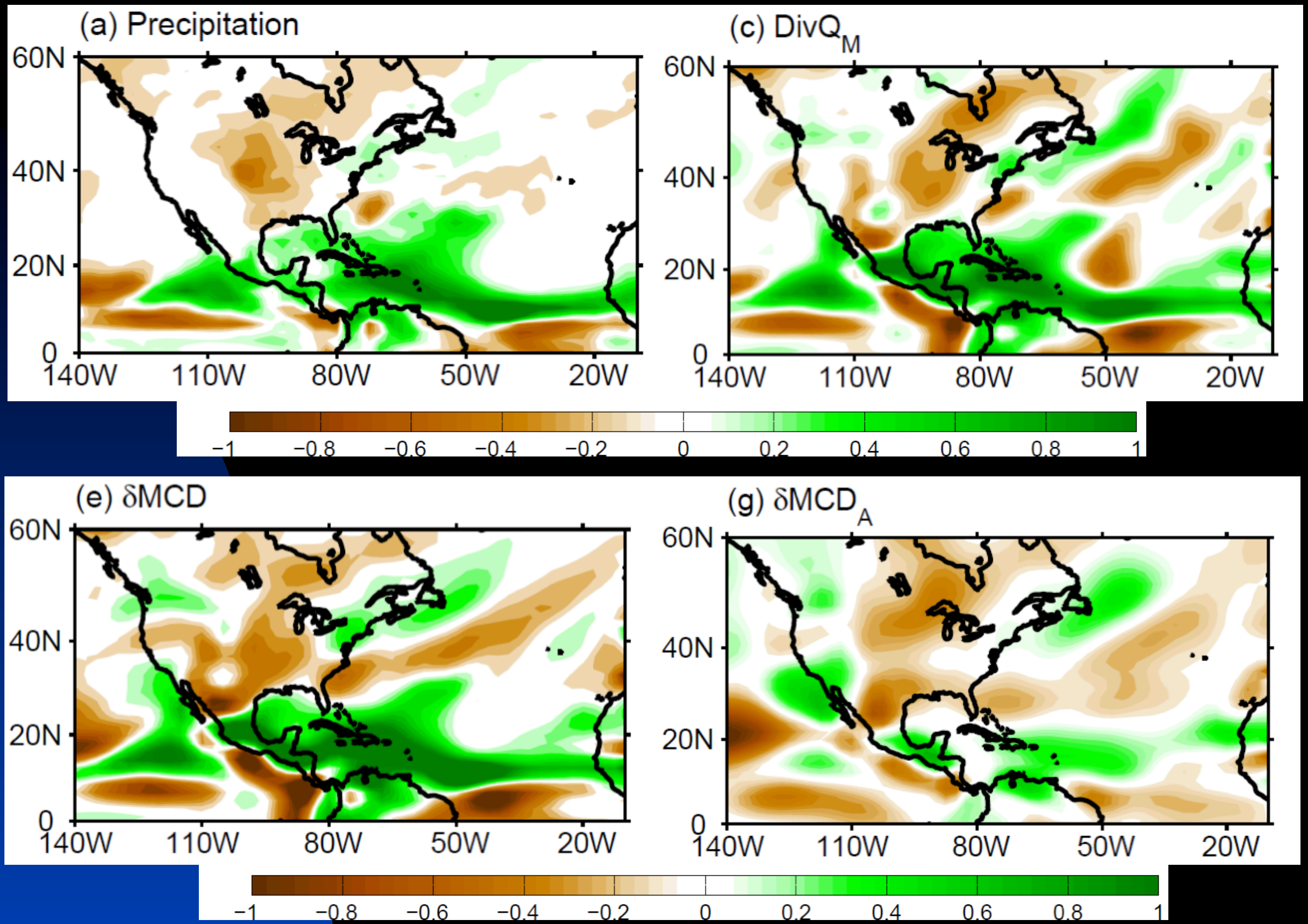
$$\delta MCD = -\frac{1}{g}\int_0^{p_s}(\overline{q}_s\nabla\cdot\delta\overline{U} + \delta\overline{U}\cdot\nabla\overline{q}_s)\,dp \equiv \delta MCD_D + \delta MCD_A$$

$$\delta TH = -\frac{1}{g}\int_0^{p_s}(\delta\overline{q}\nabla\cdot\overline{U}_s + \overline{U}_s\cdot\nabla\delta\overline{q})\,dp \equiv \delta TH_D + \delta TH_A$$



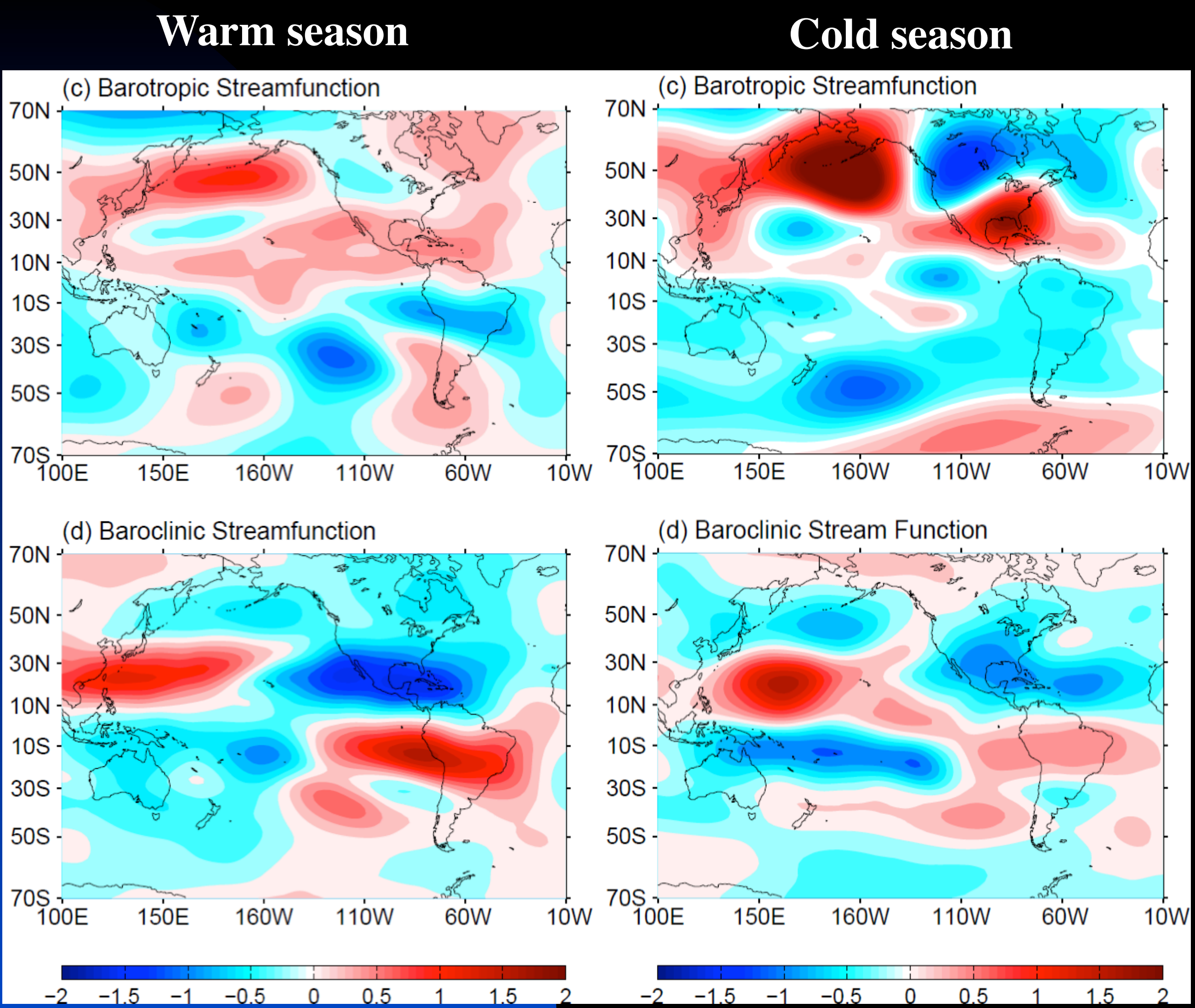
Conclusion: The wind divergence change is very important in the cold season rainfall.

Moisture Budget in the Warm Season: (LAWP-SAWP)/2 runs



Conclusion: The moisture advection by wind change is important for the warm season rainfall in the central U.S.

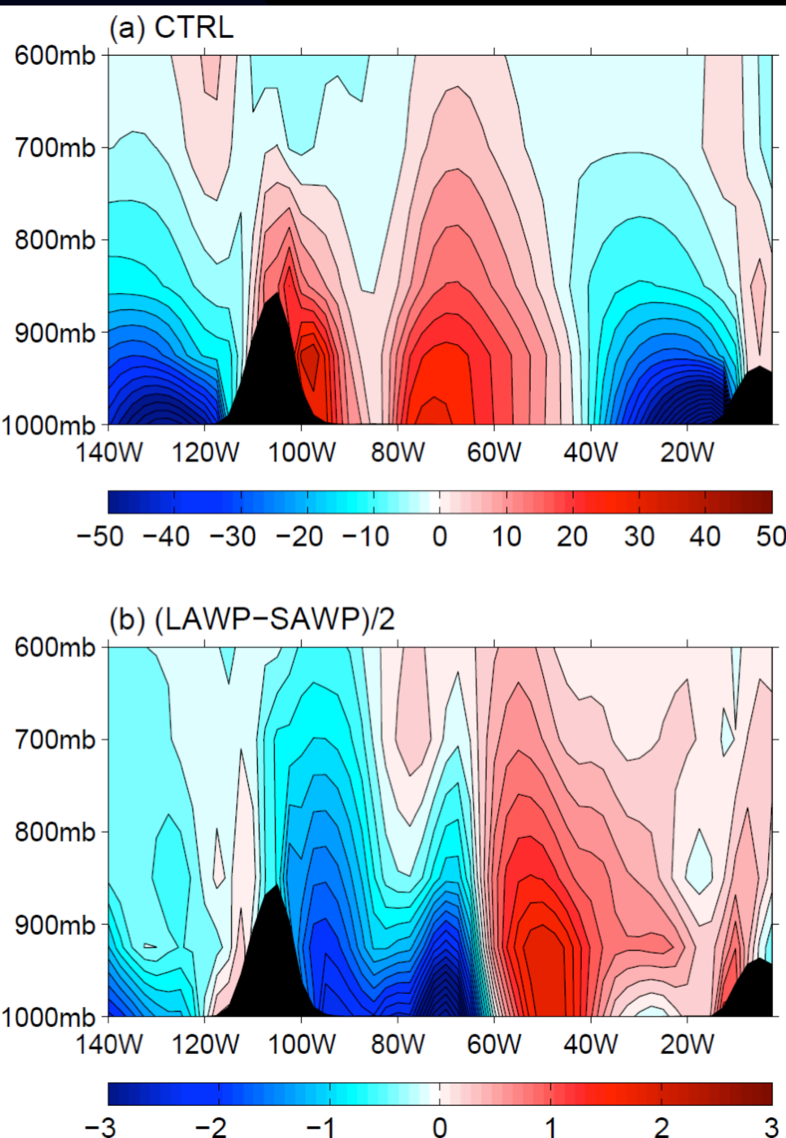
The AWP induces a local (remote) response in the warm (cold) season: (LAWP-SAWP)/2 runs



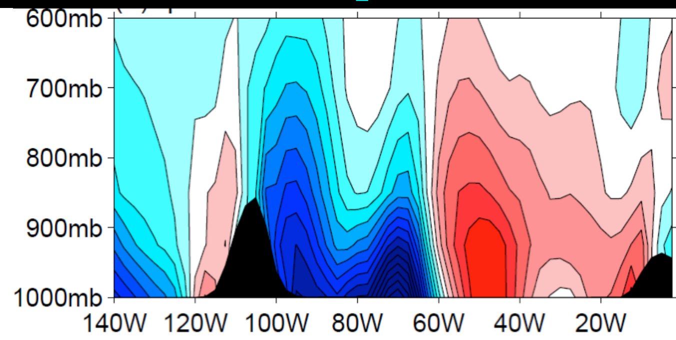
- **Baroclinic streamfunction mainly represents local diabatic heating, as shown by Gill (1980).**
- **Teleconnection effect is manifested in barotropic streamfunction.**
- **In the warm season, baroclinic streamfunction is much larger, suggesting that AWP induces a local change for rainfall.**
- **In the cold season, barotropic streamfunction is much stronger and resembles the negative phase of the PNA pattern, suggesting that AWP induces an indirect/remote effect via the Pacific.**

AWP-induced rainfall mechanism in the central U.S. during the warm season: A local response

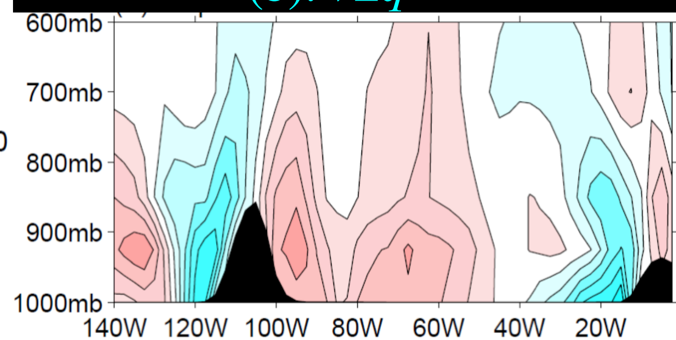
Moisture transport (qv) at 30°N



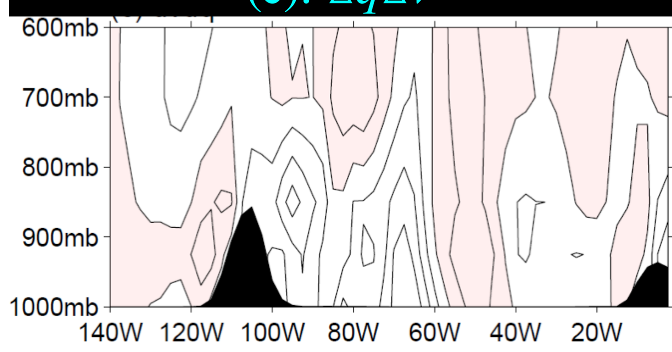
(a): $q\triangle v$



(b): $v\triangle q$

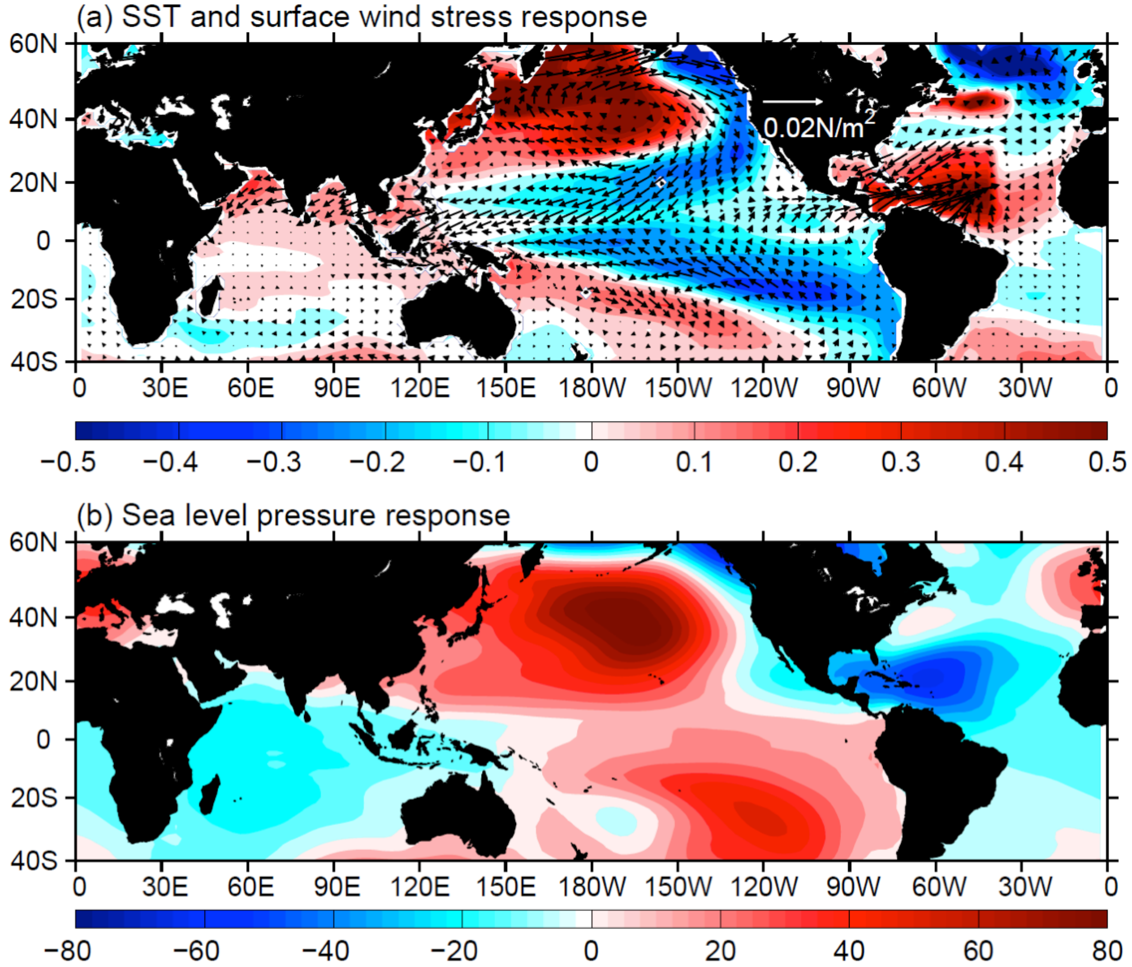


(c): $\triangle q\triangle v$



Conclusion:
Large (small) AWP reduces (enhances) the southerly Great Plains low-level jet which decreases (increases) the northward moisture transport & reduces (enhances) central U.S. rainfall in the warm season.

AWP-induced rainfall mechanism in the southwest and south U.S. during the cold season: A remote response via the Pacific

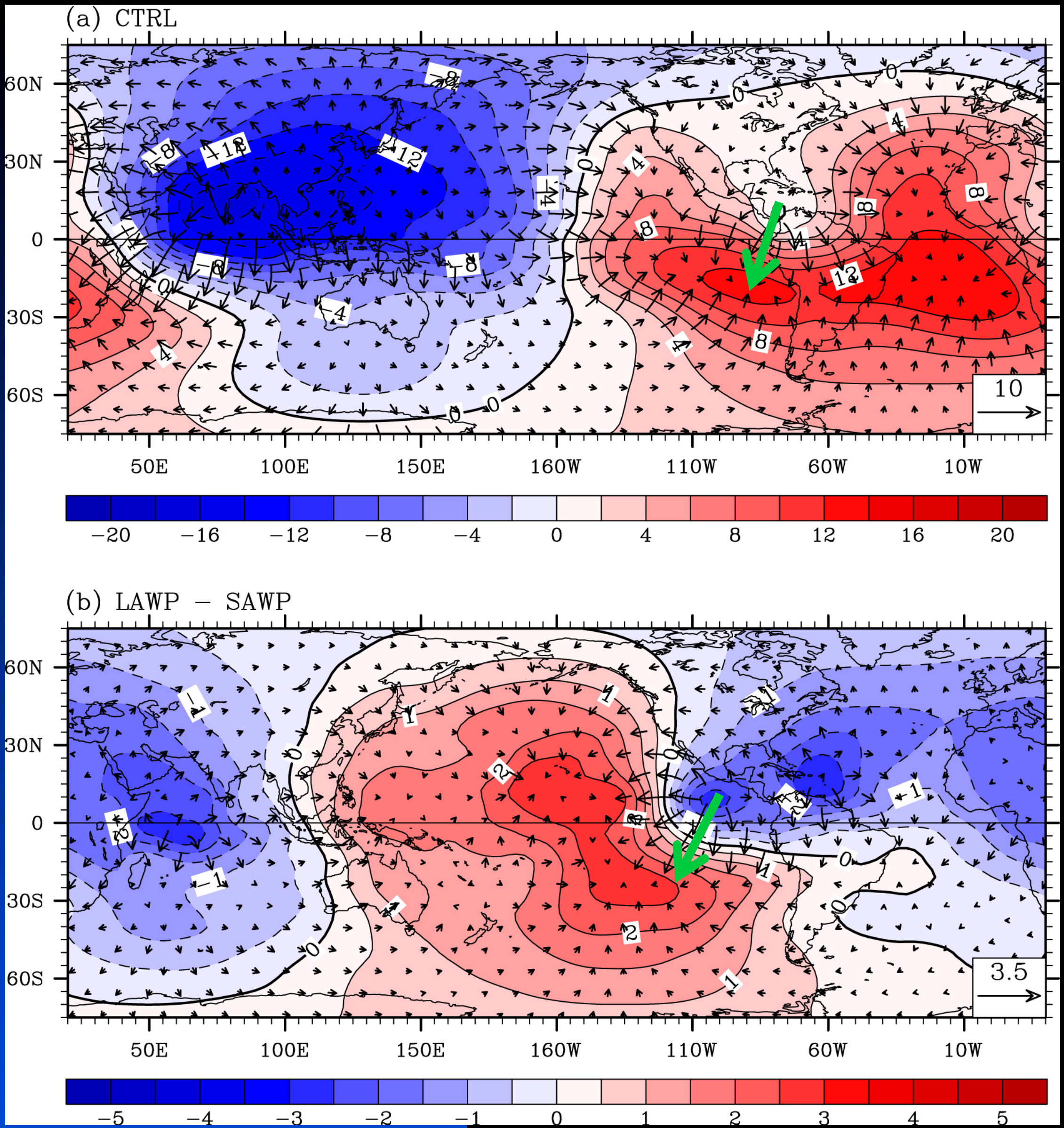


SST & wind

SLP

Conclusion: The AWP induces the cold SST anomalies in the tropical Pacific which teleconnect to influence North American rainfall in the cold season.

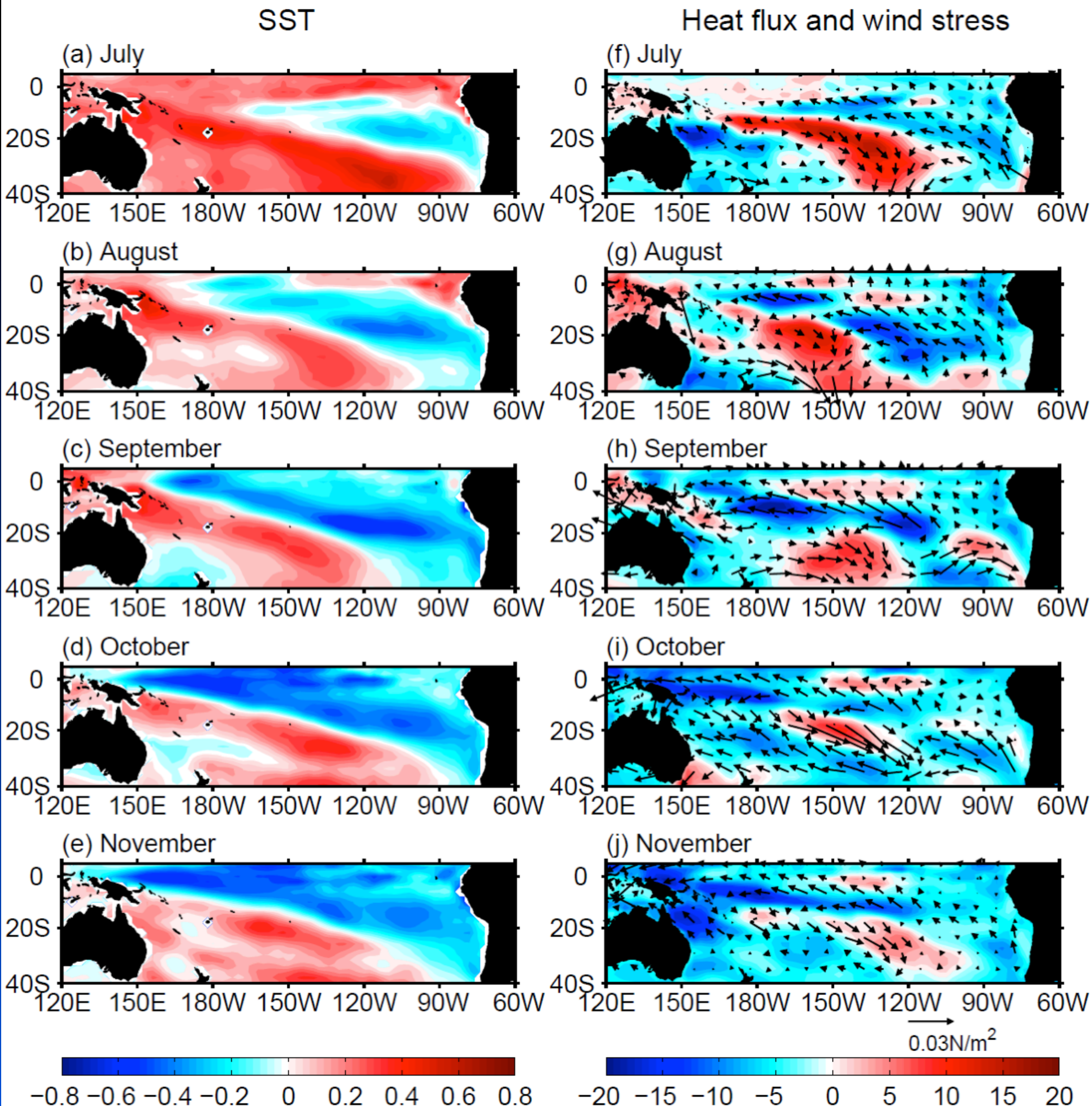
Initially, a large AWP affects the southeast Pacific via the AWP-induced regional Hadley circulation change.



Velocity potential and divergent wind at 200 mb in summer

Mean state

Effect of the AWP

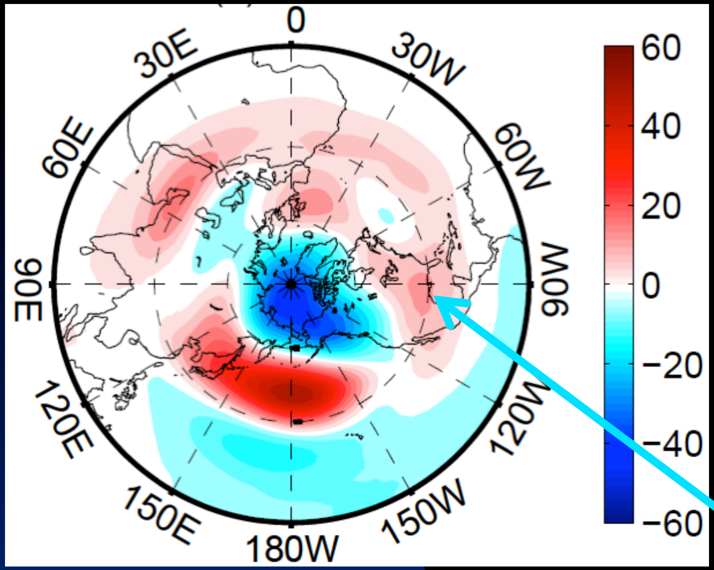


(LAWP-SAWP)/2 runs

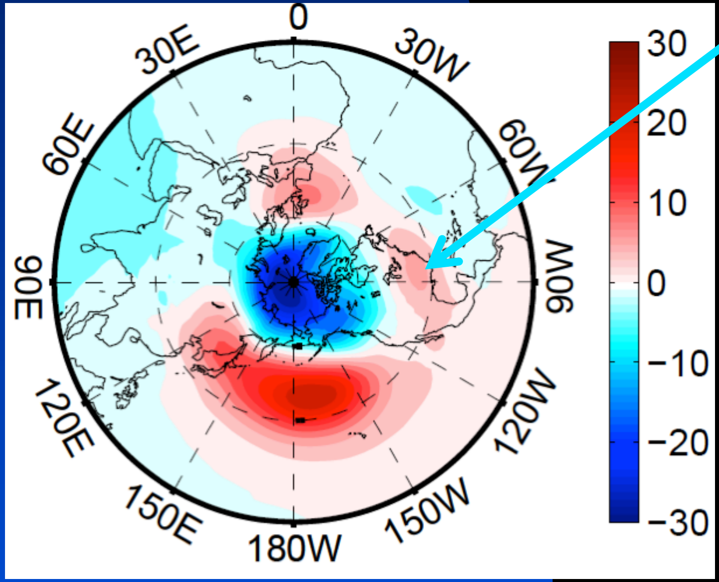
- **In summer, a AWP enhances the regional Hadley circulation.**
- **This leads to a strengthening of the easterly trade wind and cold SSTA in the tropical southeast Pacific.**
- **Then, the wind-evaporation-SST feedback further increases SSTA and propagates SSTA equatorward and westward.**
- **A La Niña-like SST pattern in winter.**

Geopotential height at 250 hPa

(LAWP-SAWP)/2 runs



Geopotential height at 850 hPa



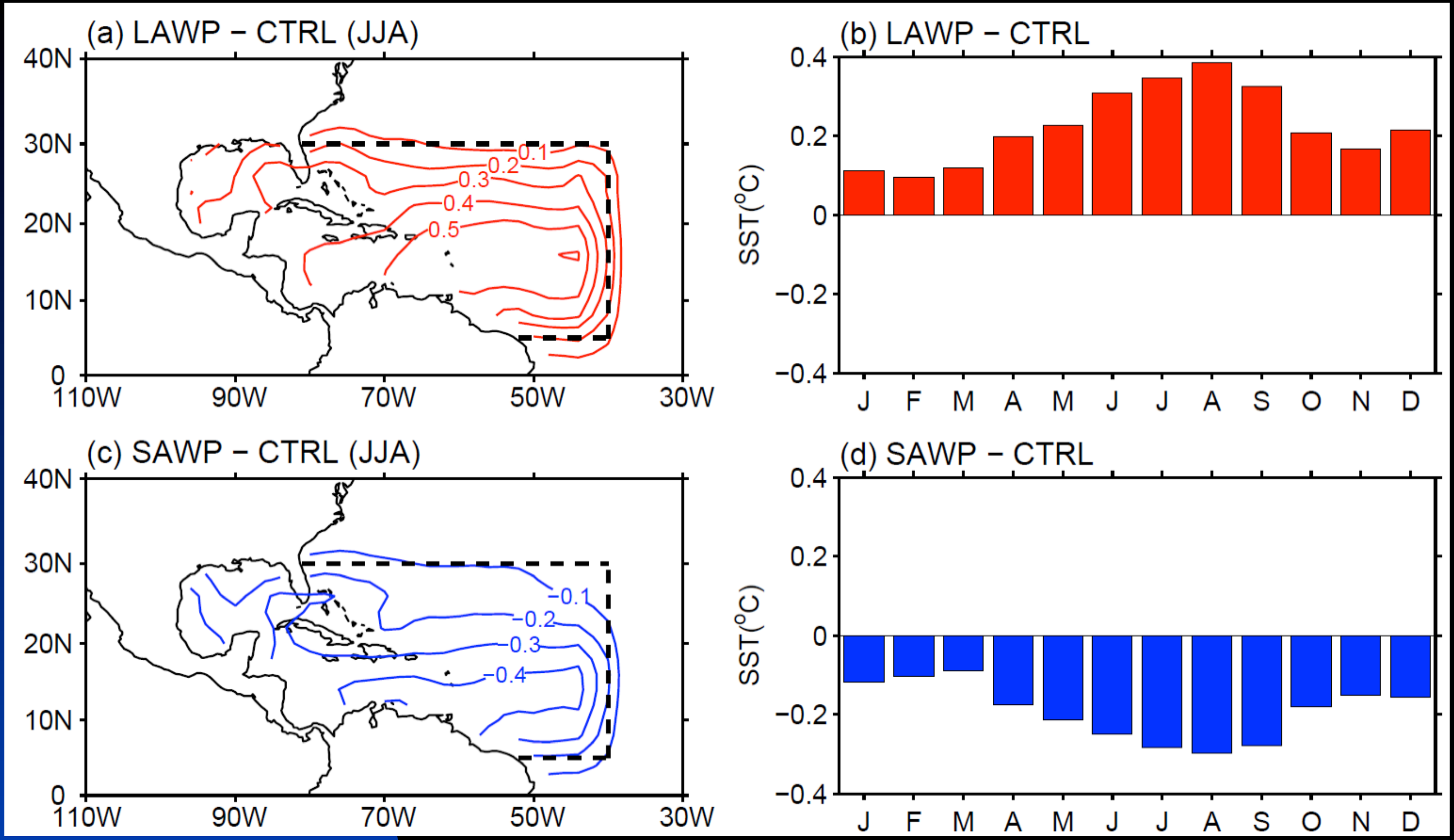
High pressure

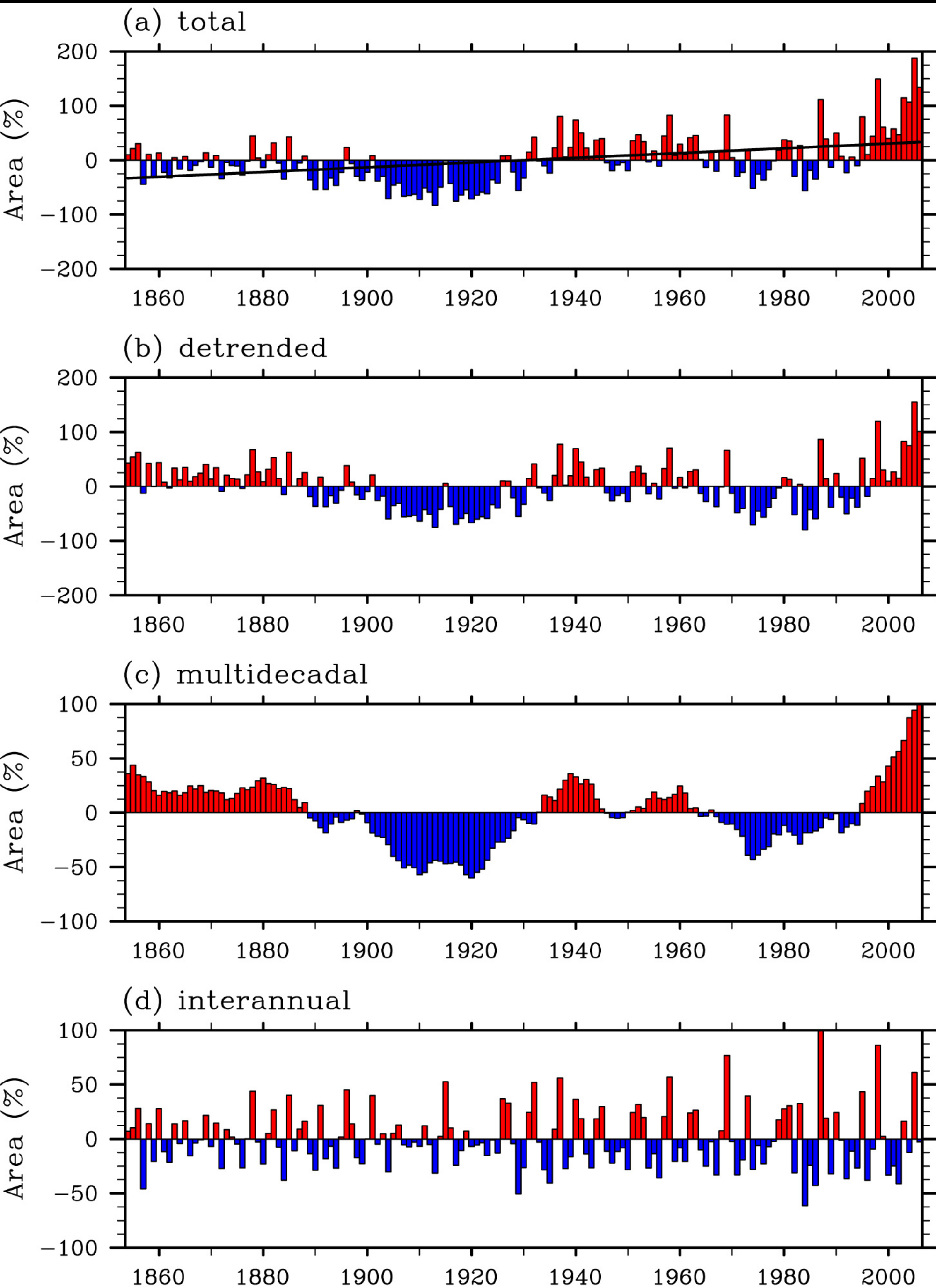
Then, the AWP-induced La Niña-like SST anomalies produce a negative phase of the PNA pattern during the cold season. Associated with the PNA are a high pressure in the southern U.S. and thus a decrease of rainfall over there.

Summary

- In the warm season, a large AWP leads to a “Gill-type” response that weakens the North Atlantic subtropical high and reduces the northward moisture transport to the central U.S., and thus decreases rainfall in the central U.S.
- In the cold season, however, the effect of the AWP on North American rainfall is through the AWP-induced change in the Pacific: A large AWP induces the cold SST anomalies in the tropical Pacific which teleconnect to reduce rainfall in the southern U.S.
- The opposite is true for a small AWP.

SST forcing differences in the AWP



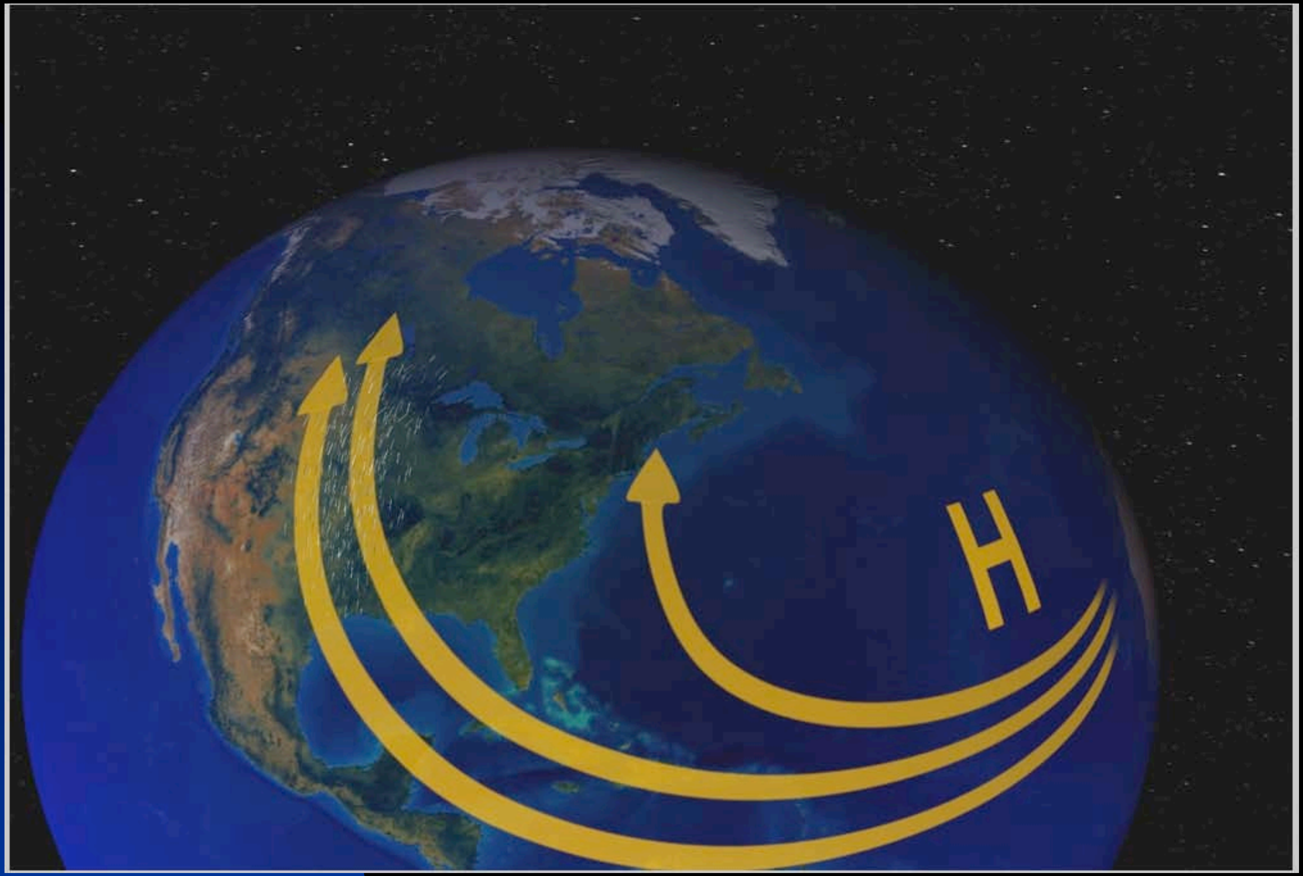


AWP (SST ≥ 28.5°C) area anomaly indices during June-November

In additional to seasonal cycle, AWP also shows interannual, multidecadal, and linear warming trend variations.

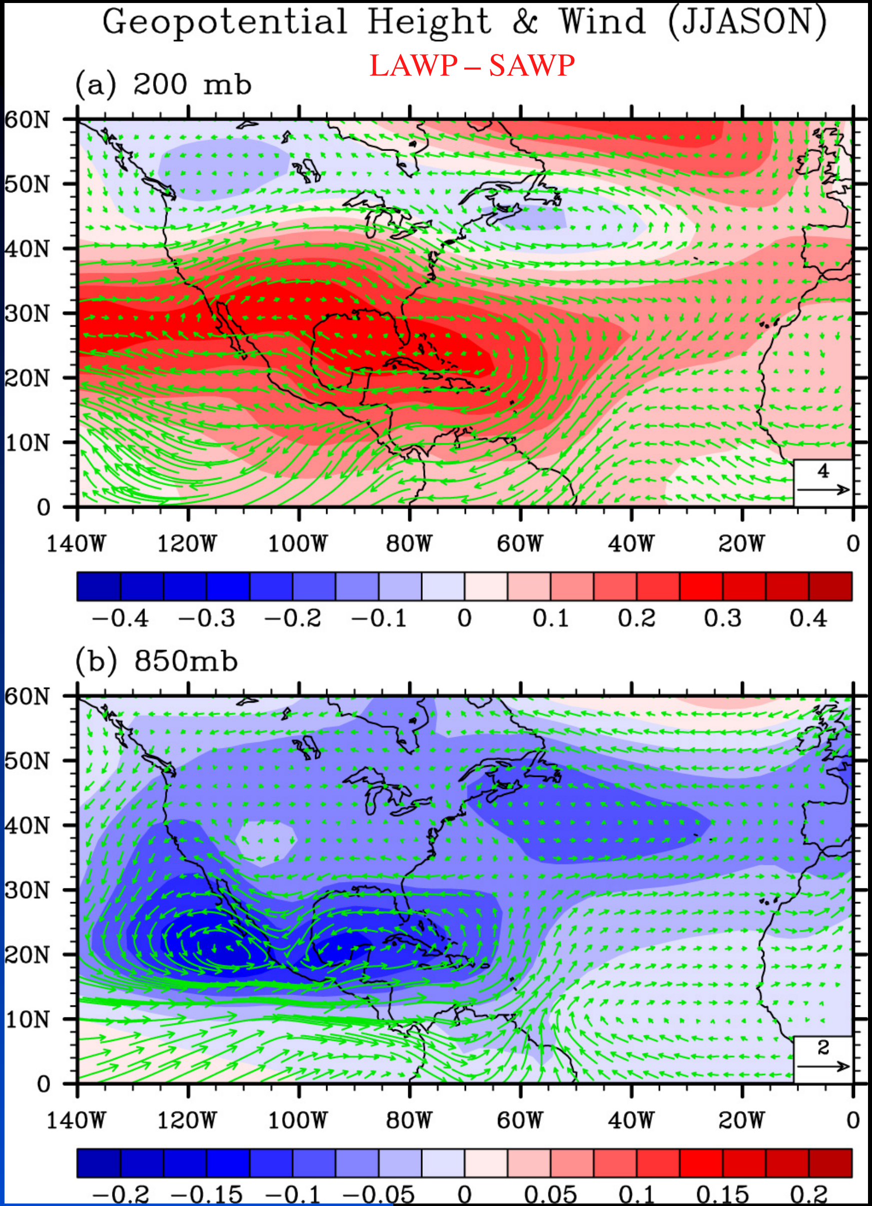
Wang et al. (2008, *G*^{3})

Why and how does AWP affect climate/hurricanes?



- AWP is a source of moisture. Atmospheric low-level flows carry moisture from AWP to the central U.S. for rainfall there.
- AWP changes the N.A. subtropical high which in turn affects atmospheric circulation and then climate.
- AWP changes vertical wind shear and instability, then hurricanes.

Gill's (1980) physics: Baroclinic response to an AWP heating.



Anomalous anticyclone at 200-mb

Anomalous cyclone at 850-mb

Wang et al. (2008, *JC*)